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The response of macroinvertebrate communities to habitat fragmentation

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THE RESPONSE OF MACROINVERTEBRATE COMMUNITIES TO HABITAT FRAGMENTATION

BY

ROSS W. WIDINSKI

THESIS

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TABLE OF CONTENTS:

ABSTRACT:

Aquatic fragmentation may be characterized as a lack of connectivity between upstream and downstream populations or sites (Page et al. 1997). Fragmentation in stream ecosystems occurs when changes in the surrounding landscape (loss/modification of riparian zone vegetation) render the in-stream habitats unsuitable for aquatic organisms. Additionally, Page et al. (1997) suggest that organisms also can be impacted or fragmented by in-stream modifications (dams, bridges) that further eliminate usable aquatic habitat and prevent movement through the aquatic system.

Intact riparian zones are of utmost importance in maintaining a healthy aquatic environment. Riparian zones with abundant vegetative cover serve to shade the stream and prevent unusually high water temperatures. Furthermore, they aid in stabilizing the stream bank, thus reducing erosion and acting as a filter to remove topsoil, pesticides, and fertilizer that would otherwise enter the stream as water drains off the croplands (Page et al. 1997). In Illinois, when modifications in prevailing riparian vegetation occurs in a riverine system it can be expected to bring about changes in the physicochemical and biological nature of the aquatic system (Townsend et al. 1997).

This study was intended to determine 1) the relationship between habitat fragmentation and biotic integrity, as characterized by the invertebrate community, in a riverine system and 2) the amount of riparian zone connectiveness that is needed to maintain a diverse river basin. These findings may lead to new management strategies or changes in restoration protocols used for assessing riparian stream ecosystems.

Nine streams, in varying degrees of riparian zone fragmentation, were selected from throughout the Embarras River basin for investigation of the relationship between

the amount of habitat fragmentation and biotic integrity as measured by invertebrate community structure. A total of 6,916 invertebrates from 36 genera were collected and identified during the course of the study period. The highest MBI scores, indicating the most polluted or disturbed environments, were found to occur where riparian cover was quite low, as well as, where it the high. When community composition was further analyzed based on feeding mechanisms it was determined that feeding groups such as percent scrappers, grazers, filterers as well as EPT taxa were not statistically significant. However, it was found that percent shredders and percent tolerant genera had a significant negative linear relationship with percent intact riparian cover.

As with the MBI scores, which indicated the least disturbed streams to have a mid-range of canopy cover, the Shannon-Weaver Index results identified streams with 40 – 60 % canopy cover to have the highest diversity scores. A higher diversity score, the more equally mixed and rich communities present. With the notable exception of scattering fork, evenness was found to have the highest scores, thus more equally abundant species / families present in the midrange of canopy cover as well.

Habitat fragmentation does affect the overall biotic integrity of a riverine system. In areas with large amounts of riparian zone fragmentation, fewer intolerant species are found indicating a poor aquatic environment. However, as observed through both the macroinvertebrate biotic index and several diversity indexes the Embarras River system needs only 40 – 60 % riparian zone cover to maintain optimum family diversity and abundance.

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LIST OF TABLES:

PAGE

LIST OF FIGURES:

INTRODUCTION:

Illinois, once dominated by prairie, savanna, wetlands, and forest, today has been transformed into mainly agricultural fields and urban areas, to the point where less than 1% of its original habitat is still intact (Page et al. 1997). In fact, it has been documented that agricultural practices alone have decimated approximately 70% of the native vegetation of Illinois over the past one hundred and fifty years (Wiley et al. 1990). This phenomenon of large, contiguous landmasses (such as Illinois' forest ecosystem) being broken up into smaller, isolated pieces or "patches" is referred to as habitat fragmentation. Fragmentation generally results in a landscape that consists of remnant areas of native vegetation surrounded by a matrix of agriculture or other developed land (Saunders et al. 1991). Habitat fragmentation has been shown to reduce the average size of patches of a given habitat, increase the distance between these patches, and finally, decrease the ratio of interior to edge within a patch (Pickett and White 1985, Reid et al. 1995, Page et al. 1997). Species that reside in the fragmented areas are also affected. For example, habitat interior species may decrease and edge specialists may increase. Moreover, species that are habitat specialists may be found only within a small portion of the patch types created within the disturbed area, whereas species that are generalists may be seen throughout the area (Kerans and Karr 1994, Carter et al. 1996).

At the present time, habitat fragmentation has been well documented as a major cause of the decline in species diversity for terrestrial ecosystems. For example, terrestrial invertebrates, such as butterflies and skippers (Lepidoptera) that reside in fragmented forests, show a marked decrease in species richness and relative abundance (Summerville and Crist 2001). In addition, it has been repeatedly found that rare or environmentally sensitive species are especially vulnerable to fragmentation (Jullien et al. 1996, Gibbs et al. 2001). Furthermore, for certain species and genera there may even be a minimum patch size necessary to maintain a viable population (Summerville and Crist 2001). Therefore, once a patch size becomes too small, certain populations may be driven to extinction, especially in the case of nonmotile species.

The effects of terrestrial fragmentation are especially prevalent in tropical forest systems. A host of organisms in tropical areas have been studied ranging from mammals such as the Golden-bellied Water Rat (*Hydromys chrysogaster*) to numerous plant species including cedro espino (*Pachira quinata*). In addition, invertebrate species (the army ant, *Eciton burchelli*), reptiles and amphibians such as the prickly forest skink (*Gnypetoscincus queenslanddiae*), and various avian species (Speckled Mourner, *Laniocera rufescens*) (Laurance 1994, Boswell et al. 1998, Robinson and Robinson 1999, Fuchs et al. 2003) have also been investigated. Yet despite the diversity of organisms studied, surprisingly similar consequences have been observed. In almost every case, relative abundance and/or species richness was reduced, as a result of habitat fragmentation, and there was a disproportionately large decrease in rare or environmentally sensitive species.

A decrease in both short-term and long-term survival is seen in many taxa. Although there are several notable exceptions such as edge specialists, most other species subjected to terrestrial habitat fragmentation, regardless of its ecological niche, have similar reductions in population size (Saunders et al. 1991, Debinski and Holt 2000, Gibbs and Stanton 2001). Short-term survival is often affected by predation. It has been documented that once prey species are flushed from their habitat or their habitat is destroyed their chances of being preyed upon increase (Andren 1994, Debinski and Holt

2000, Gibbs and Straton 2001). Long-term effects of fragmentation may include potential reductions in both the effective population size and dispersal rates of individuals between patches. As areas become increasingly fragmented the effective population size, or the number of individuals in a population that are reproducing, and the actual total census count may be greatly reduced (Wilcove et al. 1986). Migration is hindered by an organism's ability to reach a patch of suitable habitat as the landscape becomes more fragmented (Wilcove et al. 1986, Collingham and Huntley 2000).

Despite this wealth of knowledge regarding terrestrial fragmentation, much less empirical data are available on the effects of fragmentation on lotic systems. Aquatic fragmentation may be characterized as a lack of connectivity between upstream and downstream populations or sites (Page et al. 1997). Fragmentation in stream ecosystems occurs when changes in the surrounding landscape (loss/modification of riparian zone vegetation) render the in-stream habitats unsuitable for aquatic organisms. Additionally, Page et al. (1997) suggest that organisms also can be impacted or fragmented by in-stream modifications (dams, bridges) that further eliminate usable aquatic habitat and prevent movement through the aquatic system.

Intact riparian zones are of utmost importance in maintaining a healthy aquatic environment. Riparian zones with abundant vegetative cover serve to shade the stream and prevent unusually high water temperatures. Furthermore, they aid in stabilizing the stream bank, thus reducing erosion and acting as a filter to remove topsoil, pesticides, and fertilizer that would otherwise enter the stream as water drains off the croplands (Page et al. 1997). In Illinois, when modifications in prevailing riparian vegetation occurs in a riverine system it can be expected to bring about changes in the physicochemical and biological nature of the aquatic system (Townsend et al. 1997).

Among the major impacts seen in streams responding to changes in the riparian zone cover is an increase in siltation and water temperature. Siltation and runoff due to the removal of riparian vegetation and farming has led to the loss of habitat and habitat heterogeneity essential for fish and invertebrate species. Rocky areas once used for cover and breeding becomes covered with a layer of silt further affecting the viability of these populations (Page et al. 1997). Water temperature also increases as a result of loss of riparian vegetation and reduced water flow due to siltation. Increased water temperature, and the associated decrease in dissolved oxygen content, can further exacerbate the negative effects that habitat fragmentation can have on aquatic species. Additionally, oxygen levels are reduced by the effects of siltation covering the leaves of aquatic plants and preventing sufficient gas exchange (photosynthesis) causing the plants to die. Thus further reducing places available for species to hide from predators and forage (Page et al. 1997, Townsend et al. 1997).

Stream desiccation is also a result of riparian removal and agricultural activities. The rapid drainage in these agricultural areas increases the intensity and prolongs the duration of low-flow periods once the water has moved downstream (Victor and Obeibu 1985, Page et al. 1997, Thompson 2002). In areas without riparian vegetation, drought that once only caused short-term effects may lead to a prolonged period in which the streambed remains dry (Victor and Obeibu 1985, Thompson 2002). Moreover the extensive irrigation found throughout the Midwest increases the problem of stream desiccation. These low flow effects can be amplified by drought conditions as more water is removed from aquifers to supply water needed for agriculture and urban use. These significant changes to the abiotic component of an aquatic system, in response to aquatic habitat fragmentation, may influence the success of individual species within the aquatic system as well as the richness and composition of the biotic community as a whole (Townsend et al. 1997).

One such community that may be affected by stream fragmentation is the benthic invertebrate community. Assessments using benthic invertebrates have a history that extends over 150 years. However, in the last forty years there has been an increase in the use of benthic invertebrates as indicators of the quality of lentic and lotic environments due to several unique qualities of their community structure (Kerans and Karr 1994, Carter et al. 1996). This notion is perhaps best stated by Victor and Obeibu (1985) who suggest that benthic invertebrate communities are comprised of integrated populations whose structure and function reflect the underlying abiotic and biotic conditions in stream ecosystems. Thus, invertebrate communities change as species and even genera shift into and out of an area as they adjust to fluctuations in the physical or chemical makeup of the habitat. As a result, benthic invertebrates can provide valuable information about the abiotic and biotic components of a stream system and have been employed as indictors of environmental perturbations and overall lentic habitat quality (Victor and Obeibu 1985, Carter et al. 1996).

In addition, it has been shown that the sensitivity of benthic community structure also makes invertebrates an excellent indicator of anthropogenically-introduced change in aquatic systems (Carter et al. 1996). When areas are subjected to anthropogenic alterations and changes in habitat structure (e.g. reduction or change in bankside vegetation), intolerant taxa may vanish and subsequently be replaced by more tolerant and less desirable species. Therefore, benthic community structure seems to be dependant on habitat structure, types of natural and anthropogenic disturbances, and the recolonization and competitive abilities of the component species (Reid et al. 1995). For example, logging usually alters the macroinvertebrate community structure, causing changes in species composition, richness, and the proportional abundance of functional feeding groups. Specifically, there will be an increase in gatherer and scraper functional groups and a decrease in shredders (Kedzierski and Smock 2001).

Recognizing the processes by which these invertebrates feed may be helpful in understanding how their populations respond to fragmentation. Shredders are invertebrates, which convert large organic plant substrates (coarse particulate organic matter - CPOM) into fine particles (FPOM), either by fragmenting CPOM through chewing and tearing or by digestion. Approximately 60% of food ingested by shredders is converted to feces, which is utilized by other invertebrate groups, such as filter feeders and collector/gatherers (Cummings et al. 1989). Gatherers depend on FPOM for their primary food resource. They are deposit-feeders, as they generally gather fine materials, including plant, animal, and fungal detritus, from the surfaces of substrates. In addition, they may feed on the loosely held material on the tops of surface films. Finally, scrapers (grazers) depend upon attached periphyton (i.e., algae and associated flora and fauna) that develops on submerged substrates for their primary food resource (Hauer and Resh 1996). The differences in resources used accounts for the changes in macroinvertebrate community structure observed in response to changes in riparian zones. As the riparian zone vegetation is removed and replaced with grass and agricultural fields less CPOM enters the stream decreasing the food supply for shredders. Gatherers and scrappers, on the contrary, can utilize other resources such as animal and fungal detritus or periphyton and should increase in numbers and richness.

Not only are benthic invertebrates ideal for determining the general condition of a stream, but they are also useful in determining the makeup of higher trophic levels in the system because they are included among the main food sources of lentic systems. Numerous studies have shown a linear relationship between the composition of invertebrate community structure and the rest of the faunal composition (Hauer and Resh 1996, Crowl et al. 1997, Townsend et al. 1997, Marchant et al. 1999). Studies, such as those performed by Crowl et al. (1997) in both New Zealand and the United States, indicate that lotic environments that have high invertebrate species richness are able to support a significant variety of predatory organisms.

Thus, by investigating the richness and abundance of benthic invertebrates one may be able to make assumptions as to the overall "health" of a stream or a riverine system. The latter case was emphasized by Wohl et al. (1995) when they suggested that comparative studies of the structure of aquatic macroinvertebrate communities from drainage basins within the same region could reveal the variability between species distributions and environmental factors. Although many studies have examined population and community dynamics and structure, few have taken into account the biological variation among neighboring catchments. In these areas, factors such as climate, vegetation, soil type, and topography are rarely similar. As a result, comparisons of aquatic invertebrate communities must include among-stream and within-stream variation, including factors such as adjacent land use.

In this study I intended to determine 1) the relationship between habitat fragmentation and biotic integrity, as characterized by the invertebrate community, in a riverine system and 2) the amount of riparian zone connectiveness that is needed to maintain a diverse river basin. These findings may lead to new management strategies or changes in restoration protocols used for assessing riparian stream ecosystems.

MATERIALS AND METHODS:

***Study Site*:**

Nine streams, in varying degrees of riparian zone fragmentation, were selected from throughout the Embarras River basin, a 2440 square mile drainage located in east central Illinois, for investigation of the relationship between the amount of habitat fragmentation and biotic integrity as measured by invertebrate community structure. Streams were chosen by employing the Geographic Imaging System (GIS) in conjunction with the Illinois Streams Information Systems (ISIS) obtained from the Illinois Department of Natural Resources (IDNR).

The GIS technology was used to establish the general dimensions of the Embarras River basin as well as to determine topographical features. The ISIS program was employed to ascertain specific stream characteristics such as predominant land cover at bankside, width of bankside cover, as well as predominant land cover at 300 meter wide strips paralleling the stream (ISIS Users Manual 1999).

***Riparian Land Cover Determination and Stream Selection*:**

Riparian zone land cover was determined by analyzing aerial photograph slides taken by the Agricultural Stabilization and Conservation Service (ASCS). These photographs were then overlaid onto U.S. Geological Survey (USGS) 7.5-minute topographic maps to help determine the path of each stream. Eight types of land cover were identified: forested areas (> 45% canopy), areas of mixed vegetation (< 45% canopy), grassy areas (non-cultivated), agricultural areas, urban or developed areas, disturbed urban areas, reservoirs, and other water areas (ISIS users manual 1999). For the purpose of this study, riparian zones were considered intact if they were composed of greater than 45% forested canopy cover.

From these two programs, the nine streams to be used for this study were chosen based on percent forested cover, length (mi.), stream order, and the body of water into which they enter. All nine sites selected enter directly into the Embarrass River, have a stream order of roughly four, and range in length from ten to eighteen miles. Furthermore, to look at the relationship between biotic integrity and habitat fragmentation as well as determine the amount of riparian zone needed to create connectiveness within a stream system, one stream from each of ten categories representing percent of intact forested cover (> 45%) were selected (0-9%, 10-19%, 20-29%, etc; although 10-19% was not used since no streams in this system conform to this standard) for analysis of biotic integrity.

A water resistant light meter (LiCor 250 with a PAR sensor) was used to determine the amount of light reaching substrate depth as well as at surface level. A light measure was additionally taken adjacent to each site in full daylight (i.e. no forested cover) so that each stream's light measurement could be calculated as percent of full sunlight so that inter-stream comparisons could be made (surface or substrate reading / full daylight reading).

Benthic Invertebrate Sampling Protocol and Physical Parameters:

On each of 9 chosen streams, three representative sample reaches were identified and from each reach 4 replicate substrate and benthic invertebrates' samples were taken between July 22nd and October 22nd 2000 (expect in Indian Creek, Big Creek, and Allison Ditch #1 where three substrate samples were taken). This two-month sampling period allowed for recolonization after each sampling period and permitted different genera to emerge from dormancy. Each substrate sample, approximately 0.5 kilograms, was collected using a Hester-Dempsey sampler. Once collected samples were dried in a standard drying furnace and subsequently run through a series of five sieves to establish particle size. Substrate was divided into the following size classes; coarse (16-24 mm), medium (8-15 mm), fine (2-7 mm), sand (0.063-1.999 mm), silt (<0.062 mm). Sampling protocols for invertebrates followed those used by the EPA for multihabitats: the D-frame dip net approach. In addition, each site was at least 100 m. upstream from any manmade structure to minimize the overall effect of velocity, depth, and habitat quality.

Within each sampling site, the major habitat types present in the reach were sampled for invertebrates in approximate proportion to their representation within the reach. Habitat types contributing less than 5% of the stable habitat were not sampled (Rapid Bioassessment Protocols, 2nd addition). Based upon estimation of approximate habitat proportion the pool, riffle, raceway sequence was sampled with a total of twenty jabs taken starting at the further most downstream point of the reach and proceeding upstream. A jab consists of forcefully thrusting the net into a productive habitat for a linear distance of .5 m., while a kick is a stationary sampling technique accomplished by positioning the net downstream and disturbing substrate for a distance of .5 m. upstream of the net sampled (Rapid Bioassessment Protocols, 2nd addition). In addition, larger substrate was periodically examined and attached organisms removed.

Macroinvertebrate Biotic Index and Diversity Indices:

Samples were preserved in a mixture of 70% alcohol and Rose Bengal (a dye used to stain macroinvertebrate). Invertebrates collected in each sample were identified to family and the information used to determine stream biotic integrity based on benthic invertebrate feeding mechanism, abundance, richness, diversity, and evenness. Feeding mechanism is a common classification scheme for aquatic macroinvertebrates and was determined based upon invertebrate family identification (Merritt and Cummins 1996, Thorp and Covich 1991). In general, members of a particular family use similar methods in which to obtain nourishment. These methods are categorized based upon food particle size and food location, e.g., suspended in the water column, deposited in sediments, leaf litter, or live prey. This classification system reflects the major source of the food resource, either within the stream itself or from the riparian areas.

Diversity was calculated using the Shannon - Weaver Index:

$$H' = - \sum_{i=1}^{s} (p_i) (\log p_i)$$

H is the diversity score, s is the number of species, i is the species number, and pi is the proportion of individuals found in the i^{th} species. The Shannon – Weaver Index, which includes both richness and heterogeneity, is used when it is not possible to identify and count every individual in a community. In cases such as these it is necessary to take a random sample of individuals from the populations of all species present. This diversity index measures the average degree of uncertainty of predicting the species of a given individual picked randomly from a community. The Shannon – Weaver Index allows for independence of sample size because it estimates diversity from a random sample, which presumably has all species present (Schemnitz 1980).

Evenness of the sample, the measure of the actual diversity score compared to the maximum diversity score, was obtained from the formula:

$$\text{Evenness} = H'/H_{max} = H'/\ln S$$

Just as in the Shannon – Weaver Index, this evenness measure assumes that all species in the community are present within the sample. E is constrained between 0 and

1.0. The maximum diversity of a sample, found when all species are equally abundant, is represented by $H_{max.}$ S is the total number of species and ln is the natural logarithm.

Simpson's Index gives the probability that any two individuals drawn at random from an infinitely large community will belong to different species, was calculated using the following formula:

$$D_s = S\ [(n_i(n - 1))/(N(N - 1))]$$

The higher the value of D, the lower the diversity, therefore the index is usually expressed as the reciprocal = $1/D_{s.}$ S is the number of species present, n_i is the number of individuals in the i^{th} species, and N is the number of individuals in the community.

In addition, biotic integrity was determined by calculating the Macroinvertebrate Biotic Index (MBI), which is based on the pollution tolerance of an invertebrate species. Because both pollution sensitive and tolerant forms are present in "clean" waters, it is the absence of the former coupled with presence of the latter, which may indicate damage. MBI values range from 0, assigned to taxa found in unaltered streams of high water quality, to 11, which is given to those known to occur in severely polluted or disturbed streams. For example a high MBI value denotes a community with low family richness with few, if any, intolerant families present.

EPT (intolerant indictor taxa) were also calculated for each sample. EPT is the total number Ephemeroptera + Plecoptera + Trichoptera taxa present in a given sample and is an increasingly used as measure of stream water quality. EPT taxa are generally considered to be intolerant to pollution and habitat degradation. Therefore, streams with a high percentage of EPT taxa tend to have greater biological integrity and health compared to streams with low percentages (Allan 2000, Hauer and Lamberti 1996). The data collected was then used to investigate the relationship between biotic integrity and stream habitat fragmentation as well as determine the amount of riparian zone needed to create connectiveness within a stream system based on invertebrate community data.

RESULTS:

Physical Parameters:

With few exceptions, streams with less fragmentation (i.e. more canopy cover) had a greater the amount of fine, medium, and coarse gravel (Figure 1). Antithetically, locations with less riparian cover had a higher build-up of sand in their streambeds (Figure 2). In both Scattering Fork and Greasy Creek abnormally high percent of coarse material was observed, however, in each case one large field rock accounted for the majority of the coarse material weight.

Light data (the amount of light reaching the stream) indicates that streams with 39% or less riparian cover have at least 60% of the day's full sunlight striking their surface and up to 39% striking their substrate. Streams with 40% or more cover all have less than ten percent of full sunlight striking both their surface and substrate (Figure 3 and 4).

Benthic Macroinvertebrate Community Characteristics:

A total of 6,916 invertebrates from 36 genera were collected and identified during the course of the study period; the amount collected at each stream ranged from East Branch Embarras with 3681 specimens to Brushy Fork with 266 examples (Table 1). Macroinvertebrate Biotic Index values varied from 5.116 (Polecat Creek) to 6.116 (Allison Ditch #1). The highest MBI scores, indicating the most polluted or disturbed environments, were found to occur where riparian cover was quite low, as well as, where it the high. Streams with 40–60 % intact riparian forest cover (Greasy Creek, Brushy Fork, Polecat Creek) had the lowest overall MBI scores ($r^2 = 0.53$; $p<0.01$; Figure 5). When community composition was further analyzed based on feeding mechanisms it was determined that feeding groups such as percent scrappers, grazers, filterers as well as

EPT taxa were not statistically significant. However, it was found that percent shredders ($r^2 = 0.45$; $p<0.05$) and percent tolerant genera ($r^2 = 0.43$; $p<0.05$) had a significant negative linear relationship with percent intact riparian cover (Figure 6 and 7).

Diversity Indices:

Diversity calculated using Shannon-Weaver Index ($r^2 = 0.37$; $p<0.01$) was shown to vary from 1.83 in Brushy Fork to .845 in the East Branch Embarras. As with the MBI scores, which indicated the least disturbed streams to have a mid-range of canopy cover, the Shannon-Weaver Index results identified streams with 40 – 60 % canopy cover to have the highest diversity scores (Figure 8). A higher diversity score, the more equally mixed and rich communities present. Additionally, the Simpson Diversity Index does not show significance in regards to macroinvertebrates and their relationship to cover (Table 2). Finally, evenness was shown to vary from .250 in Big Creek to .64 in Allison Ditch. In general, the highest evenness scores, and thus the invertebrate communities with a measure of biodiversity that is fairly equal numerically, are found to occur in streams with a midrange of riparian zone cover
($r^2 = 0.32$; $p<0.01$; Figure 9).

The data indicate that streams with with less fragmentaion have a greater the amount of fine, medium, and coarse gravel; and thus a wider variety of habitat types. In addition these streams with a greater amount of riparian zone cover receive less light at both surface and substrate levels. Streams with 40–60 % intact riparian forest cover had the lowest MBI scores indicating a less polluted environment, the highest diversity scores based upon the Shannon-Weaver Index, and the highest evenness scores. Unexpectedly, percent shredders and percent tolerant genera had a significant negative linear relationship with percent intact riparian cover.

DISCUSSION:

Several studies have indicated that invertebrates are especially sensitive to riparian zone fragmentation (Reid et al. 1995, Carter et al. 1996). In fragmented environments benthic invertebrate numbers have been shown to vary based on their feeding method and sensitivity to environmental changes (Kedzierski and Smock 2001). However, the amount of riparian zone fragmentation needed to disrupt the faunal composition has not been well documented. Thus, the goals of this study were to: (1) determine the relationship between habitat fragmentation and biotic integrity in a riverine system, (2) the amount of riparian zone connectiveness that is needed to maintain a diverse river basin, and (3) suggest management strategies regarding riparian zone reforestation. Agriculture and the process of clear cutting and subsequent agricultural development leads to a legacy of fragmented patches of vegetation across the entire landscape. Because these patches or fragments are situated in different positions in the landscape, vary is size, soil types, and vegetations it is difficult to make inferences across large expanses of land. However it has been documented that in smaller areas, such as a small river cache, similarities between fragments may allow such inferences to be made (Saunders et al. 1990). Thus, the nine streams selected from the Embrassas River basin, which differ almost exclusively in the amount of riparian zone fragmentation, provide an excellent opportunity to help determine both biotic integrity and diversity within a fragmented system.

Species richness and various diversity indices are often used to aid in the determination of community composition in a particular environment. When fragmentation occurs there is usually a decrease in the overall values for these indices. Besides changes in species composition there is often a related change in genera and/or family composition as well (Victor and Obeibu 1985, Thompson 2002). Based on the invertebrate sampling performed on the three sites in each of the streams it was determined that family richness was, in fact, not statistically different among streams. This point is best illustrated by the fact that 6 of the 9 streams sampled contained 20 to 22 families of benthic invertebrates. One possible explanation for this finding is that in many of the streams studied several families were represented by only a single individual. Since richness documents only the number of families present and not the number of individuals colleted in each of the families, family richness may not be an index for determining the effects of riparian zone fragmentation. For example, there were 333 specimens collected from 18 families in Big Creek but 297 belonged to a single family and 10 families had just 1 or 2 individuals. Another prime example of this is Indian Creek where 244 of 300 individuals collected belonged to a single family. By contrast in Polecat Creek, 9 families had at least 10 individuals collected and 3 were found to have over one hundred specimens.

A second possible explanation for the occurrence of unexpected families may involve increased flow regime during rainstorm events. As water levels increase, riffles and sometimes-even pools, become raceways. These raceways consist of fast moving water that is capable of dislodging invertebrates from their typical habitats and relocating them in less desirable locations. This dislodgment of invertebrates was documented by Holomuzki and Biggs (2000) in their study of mayflies and caddisflies and reiterated in Miyake et al.'s (2003) work on various taxa in streams in Japan. Each of these studies documented a change in community structure before and after major storm events. In both studies invertebrates not typically located in certain habitat types were found to have been swept there after an abrupt increase in steam flow. In fact, of the streams studied in the Embarras River cache, several of the families represented by just one individual were species commonly found in riffles such as members of Ephemeroptera, Plecoptera, and Trichoptera who can be easily displaced during strong flow regimes caused by an influx of rainwater. It should be noted that fragmentation, and its related reduction of pools and riffles due to increased runoff and sedimentation, further exacerbate these increased flow conditions as raceways are formed and may enhance macroinvertebrate displacement.

In addition to species richness several diversity indices were calculated. The Simpson Diversity Index did not show significance among streams with varying amounts of canopy cover, although there was a general trend for greater diversity in streams with between 40 - 60 % riparian zone fragmentation. The Shannon-Weaver Index also identified streams with 40 - 60 %canopy cover to have the highest diversity scores. Thus, these streams (Greasy Creek, Brushy Fork, and Polecat Creek) have a more equally distributed and rich community present within their sample sites. For example Brushy Fork, with 55.6 % cover, had a Shannon-Weaver score of 1.83 indicating a fairly diverse stream macroinvertebrate community (results between 1.5 and 3 are common). However streams with little riparian zone, such as the East Branch Embarras with 22.3 % cover and a diversity score of 0.845, and streams with very little fragmentation, such as Big Creek with 98.2 % of its riparian zone intact and a diversity score of 0.722, have fairly low diversity scores indicating very little uncertainty in the next family to be observed.

The diversity indices may have been highest at intermediate levels of riparian zone fragmentation for several reasons. These streams provide habitat for a wide variety of invertebrate species due to their diverse substrate composition and flow composition.

The substrate in these streams is, in general, a combination of fine, medium, coarse, and decaying organic matter that, because of its variety, supports a wide range of invertebrate including scrapers (grazers), gatherers, shredders and filter feeders (Bis and Higler 2001). In streams with a low degree of riparian zone cover (0-20%) the substrate is generally composed of silt and sand which limit the types of benthic invertebrates these areas can support. The loss of scrapers and filter feeders may be due to the fact that they do not have the proper habitat, periphyton attached to large substrate types and clear water, in order to establish sustainable populations (Namba 1999, Bis and Higler 2001). Conversely, streams with relatively little riparian zone fragmentation (80-100 percent intact riparian cover) may have a lower diversity score because of competition between invertebrates for these high quality areas. R.G. Death (1995) states that grazers and filter feeders will dominate areas of high stability by out competing other species especially gatherers. In addition, in areas with high and low degrees of fragmentation there are fewer habitat types available for invertebrate colonization. When riparian zone fragmentation occurs in the 40 – 60 % range there are both high quality and low quality habitat types available allowing a greater diversity of species and families to occupy these zones.

The highest diversity scores associated with streams with intermediate fragmentation correspond well to the intermediate disturbance hypothesis. Connell (1978) proposed his intermediate disturbance hypothesis which states those communities in unstable habitats will be initially dominated by species with superior colonization abilities and then gradually replaced by competitively superior, but more sedentary species as stability increases. In addition, the hypothesis proposes that biodiversity is highest when disturbance is neither too rare nor too frequent. The notion that disturbance can increase biodiversity opposes the earlier hypothesis that diversity is highest in undisturbed ecosystems.

The 4 main reasons for high diversity at levels of intermediate disturbance include the fact that there is more heterogeneity within patch or habitats at intermediate disturbance levels. Secondly, on a landscape scale, there are more patch types at intermediate disturbance levels, therefore more species. Next, there may be an overlap of early successional species and late successional species. Lastly, the disturbance prevents competitive exclusion and thus allows high niche overlap at intermediate disturbance (Connell 1978).

Using Connell's research as a model Hildrew and Townsend (1987) illustrated that sessile grazers and filter feeders will dominate communities in stable sites with high productivity whereas mobile species will become increasingly more dominate, as stability is lost. Finally, a recently proposed model states that highly disturbed and/or homogeneous habitats will be dominated by highly mobile species, while sedentary species will be more common in temporally stable and/or patchy habitats (Death 1995). In general these aforementioned conditions are seen in this study. Streams, such as Polecat creek with approximately 60 % riparian cover, show a great deal of heterogeneity within a patch, which in part, may be due to intermediate levels of disturbance. In addition, the streams studied with midlevels of riparian fragmentation contain numerous types of habitats (runs, riffles, and pools) increasing the chance of high species diversity. In areas surveyed with a high degree of siltation and habitat fragmentation, large numbers of motile families, such as Chironomidae, were observed. Conversely, in study sites with large amounts of riparian zone cover, a greater number of filter feeders and grazers, such as Corbiculidae, were observed. These findings may also be related to tolerance. Chironomidae and related families are tolerant of changes to their environment, while filter feeders and grazers are considered intolerant species and fare poorly in altered habitats. The findings in the Embarras River system indicate that tolerant species are, in fact, more common in disturbed areas. The data indicate that streams with little fragmentation and streams with a great deal of fragmentation do not have as a diverse or even community structure in comparison to those in the mid-range of intact forested canopy cover and may be in large part due to a lack of habitat heterogeneity and competition between invertebrate families for resources.

Another possible explanation for these observed differences in diversity is the historical makeup of the habitat in and around the Embarras River Basin. Although Illinois is widely regarded as the "prairie state", grasslands did not compose the entire state. Lawrence County, located near the terminus on the Embarras River, was surveyed in 1804-1805 and again in 1818-1819. Using these data it was determined that this county was composed of approximately 45% forest (Edgin 1996). Another such study was preformed in Crawford County, located to the south east of the river basin, by Edgin and Ebinger (1997). After comparing notes from field studies performed from 1804 to 1821 in was determined that Crawford County was originally over 40% woodlands. Coles County, where a great deal of the river system is contained, also had a similar study under taken by J. Ebinger (1987). In this study Dr. Ebinger reviewed county surveys taken in 1821 and 1822. From these surveys it was concluded that Coles County contained over 40% forested cover over 175 years ago. Thus, it would seem that both within and around the river basin woodlands historically made up 45 % of the landscape. Although the river basin undoubtedly had a higher percentage of woodlands, invertebrate communities found in the Embarras River basin may still be inclined to be more diverse in conditions containing roughly 40% woodlands. This studies finding suggest that invertebrate communities are the most diverse in streams containing 40 – 60% intact riparian zone cover. This fits the historical data of 40% wooded landscape in the Embarras River basin and the notion that streams riparian zones will contain a higher percentage of woodlands.

In addition to richness and diversity scores, percent abundance of shredders, grazers, gatherers, and scrapers was determined. Shredder populations were found to decrease significantly with an increase in riparian zone cover (which was not expected to occur), while grazer, gatherer, and scraper populations were shown to have no relationship with the amount of intact riparian zone cover. Gatherers, who depend upon fine particulate organic matter (FPOM), may be insignificant due to a lack of resources being created by shredders. FPOM is created principally as shredders break down leaves and a lack of shredders in areas with large amounts of riparian forest may be preventing gatherer populations for reaching expected sizes. Furthermore, since gatherers also consume animal and fungal detritus, their populations may be kept at levels, which render them statistically insignificant. Grazers and scrapers feed primarily upon algae and associated flora and fauna that are found in many habitat types. In areas with large amounts of riparian zone fragmentation algae may be located near the surface and attached to stream banks, whereas, in areas with little fragmentation algae may be found attached to rocks and downed trees (Cummings et al. 1989, Hauer and Resh 1996). The availability of food material throughout all stream types may have resulted in the inability to distinguish differences in feeding mode abundances among streams.

We would assume that shredder populations would be quite large in areas with a high degree of riparian zone cover due to a large influx of leaves (CPOM) into the river system, however, fewer shredders were collected in areas with a high degree of riparian zone cover. One possible explanation for this observation may be due to an increase in flow regime during fall rainstorms. During several of the sampling seasons there were numerous storms, which may have caused the invertebrates or their food supply to be washed down stream. Another explanation for a decreased number may be due to environmental tolerances of shredder families. Many invertebrates classified as shredders are tolerant to both biotic and abiotic changes to their habitats and as a result can survive in areas with fine substrate and a lack of riparian zone cover (Meglitsch 1972). These shredders may in fact be consuming vegetation from the surrounding farm fields, such as corn and soy leaves, which may be more readily available through the year.

Macroinvertebrate Biotic Index (MBI) is based on the pollution tolerance of an invertebrate species. Because both pollution sensitive and tolerant forms are present in "clean" waters, it is the absence of the former coupled with presence of the latter, which may indicate damage. It was determined that streams with 40 - 70 % intact riparian zone cover (Greasy Creek, Brushy Fork, Polecat Creek, and Muddy Creek) had the lowest MBI score indicating the presence of a greater number of pollution sensitive species. Thus, these streams would be considered more habitable for species with sensitivity to pollution or habitat degradation. One possible explanation for the lowest, and thus best, MBI scores in the mid range of riparian zone fragmentation may be due to the sensitivity of the species in question. In areas with relatively low amounts of riparian zone cover the affects of siltation and water temperature and its associated affects on oxygen content may eliminate intolerant invertebrates species used in the calculation of the MBI index, such as Ephemeroptera, Plecoptera, and Trichoptera. In areas with high amounts of riparian zone cover relatively few shredders were present which may limit the processing of the organic matter and may cause a gradual buildup and slow decay of leaves and other organic matter in these areas, which leads to a reduction in overall energy available in the system and a possible reduction in the number of invertebrate families.

The data collected indicates that there in a greater abundance of most families in the midrange of intact riparian zone cover. This may be in large part due to a greater range of both substrate types (fine, medium, and coarse grave) as well as a variety of reach types (pools, runs, and riffles). This wide variety of habitat types allows for both tolerant and intolerant families to locate areas, which suit both their environmental and feeding mechanism needs. In addition, since invertebrates of all feeding modes can be found within a reach there are most likely a wide variety of resources (CPOM, FPOM) available further enhancing conditions for numerous invertebrate families. Given the recent concern about environmental conditions both within our country and state this data may be used for management purposes.

Management strategies for aquatic ecosystems must be applicable to the entire watershed. If local corrections are made without considering both upstream and downstream locations, only partial or temporary remedies will be made (Page et al. 1997). With this in mind, management of fragmented ecosystems must contain two basic components. First, the management of the natural system, or internal dynamics of the fragmented areas, must be taken into account. Secondly, management of external influences, such as farming and pollution, on the natural system must be considered (Saunders et al. 1990, Dobson and Cariss 1999). The overriding goal of conservation management is usually to maintain species diversity in an attempt to maintain representative examples of each ecosystem or community type present before fragmentation.

Conservation ecologists must know the distributions of species and communities in the habitat in question. Thus, ecologists must either study similar habitats in pristine conditions and use them as a guide for restoring species diversity in the fragmented area or study a fragmented area and make the best of the species diversity available. Once the ideal conditions for the stream have been established the amount of intact riparian zone needed to support the desirable species diversity must be determined. Next, the system must be managed in such a way as to maintain this optimal level of species diversity. Typically this requires the removal of certain vegetation around the stream, such as corn, and the planning of other types such as a representative community of native trees. Subsequently, priorities for management must be established. For example, should one stream be entirely restored or should several be partly returned to a more natural state. Finally, this management of both the species and the habitat must be continuous (Saunders et al. 1990, Dobson and Cariss 1999).

One of the effects of this study has been the determination of the relative species abundance throughout the Embarras River cache. Additionally, it has been determined that in order to maintain the highest levels of species and/or family abundance in the streams sampled, 40 – 60 % riparian zone cover must be provided. Since most benthic invertebrates are capable of colonizing new habitats, at least at the larval stage, conservation ecologists must prioritize and choose to manage the surrounding riparian habitat before we deal with the invertebrates and stream systems. Once this degree of riparian zone reforestation has occurred, the negative affects of siltation and increased water temperature will be reduced allowing for eventual invertebrate colonization. After the riparian zone has been reestablished both the conservation managers and the farmers, whose fields these streams lie adjacent to, must take an active role in maintaining stream condition by not farming up to the edge of the stream and preserving the riparian environment.

I conclude that habitat fragmentation does affect the overall biotic integrity of a riverine system. In areas with large amounts of riparian zone fragmentation, fewer intolerant species are found indicating a poor aquatic environment. However, as observed through both the macroinvertabrate biotic index and several diversity indexes the Embarras River system needs only 40 – 60 % riparian zone cover to maintain optimum family diversity and abundance. It would seem that restoration to hundred percent riparian cover, as has been done in the past, is not necessary and is not cost efficient. Thus the management decision to restore the riparian zone along the Embarras River cache should be implemented. However, it should be noted that the width of the riparian zone needed to maintain these findings has yet to be determined. In addition, these findings may only be relevant to the Embarras River system and should not be superimposed on to other river systems.

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Table 1: Community structure of the nine streams studied in the Embarras River basin.

Stream	% Intact Cover	Inverte-brates	MBI	Percent Shredder	Percent Scrapper	Percent Gatherer	Percent Tolerant	Percent Filterer	% EPT
Scattering Fork	0.34	554	6.052	0.049	0.104	0.594	17.217	0.163	0.079
East Branch Embarras	22.28	3681	5.466	0.013	0.056	0.338	14.202	0.315	0.087
Allison Ditch #1	34.89	299	6.166	0.040	0.308	0.288	33.108	0.324	0.070
Greasy Creek	47.06	451	5.510	0.024	0.067	0.614	16.555	0.271	0.080
Brushy Fork	55.62	338	5.629	0.019	0.098	0.541	14.343	0.255	0.105
Polecat Creek	62.71	479	5.116	0.021	0.063	0.553	1.480	0.336	0.119
Muddy Creek	73.98	471	5.717	0.004	0.015	0.892	0.851	0.079	0.104
Indian Creek	85.93	377	5.920	0.013	0.013	0.716	6.000	0.030	0.064
Big Creek	98.22	338	5.970	0.018	0.027	0.899	2.703	0.027	0.024

Table 2: Diversity indices calculated for selected streams in the Embarras River basin.

Stream	% Intact Cover	Shannon-Weaver	Evenness	Simpson	Richness
Scattering Fork	0.34	1.654	0.521	3.418	24
East Branch Embarras	22.28	0.845	0.282	4.395	20
Allison Ditch #1	34.89	1.918	0.640	4.718	20
Greasy Creek	47.06	1.486	0.488	2.657	21
Brushy Fork	55.62	1.830	0.611	3.949	20
Polecat Creek	62.71	1.515	0.490	3.052	22
Muddy Creek	73.98	0.748	0.301	1.426	12
Indian Creek	85.93	1.314	0.439	2.198	20
Big Creek	98.22	0.722	0.250	1.294	18

Figure 1. Percent substrate type plotted against percent riparian zone cover. In general, streams with less fragmentation contained a greater amount of fine, medium, and coarse gravel

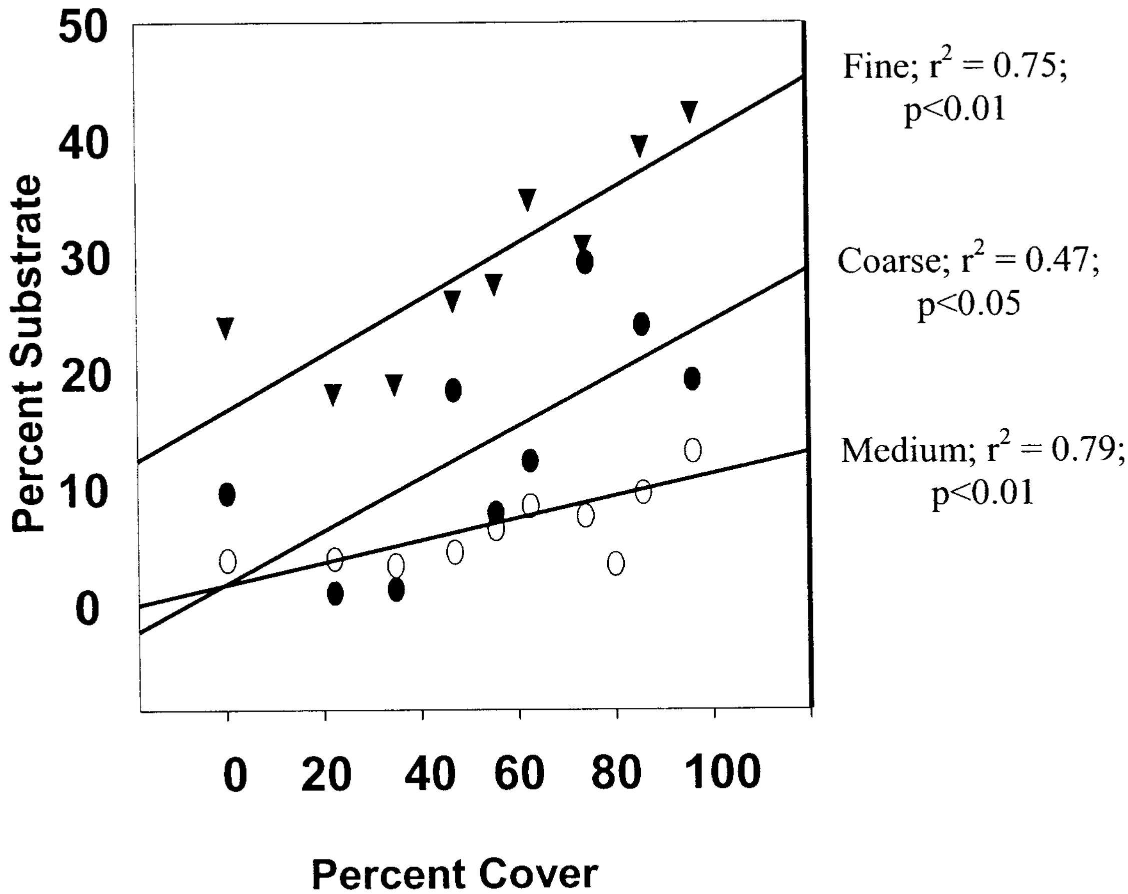
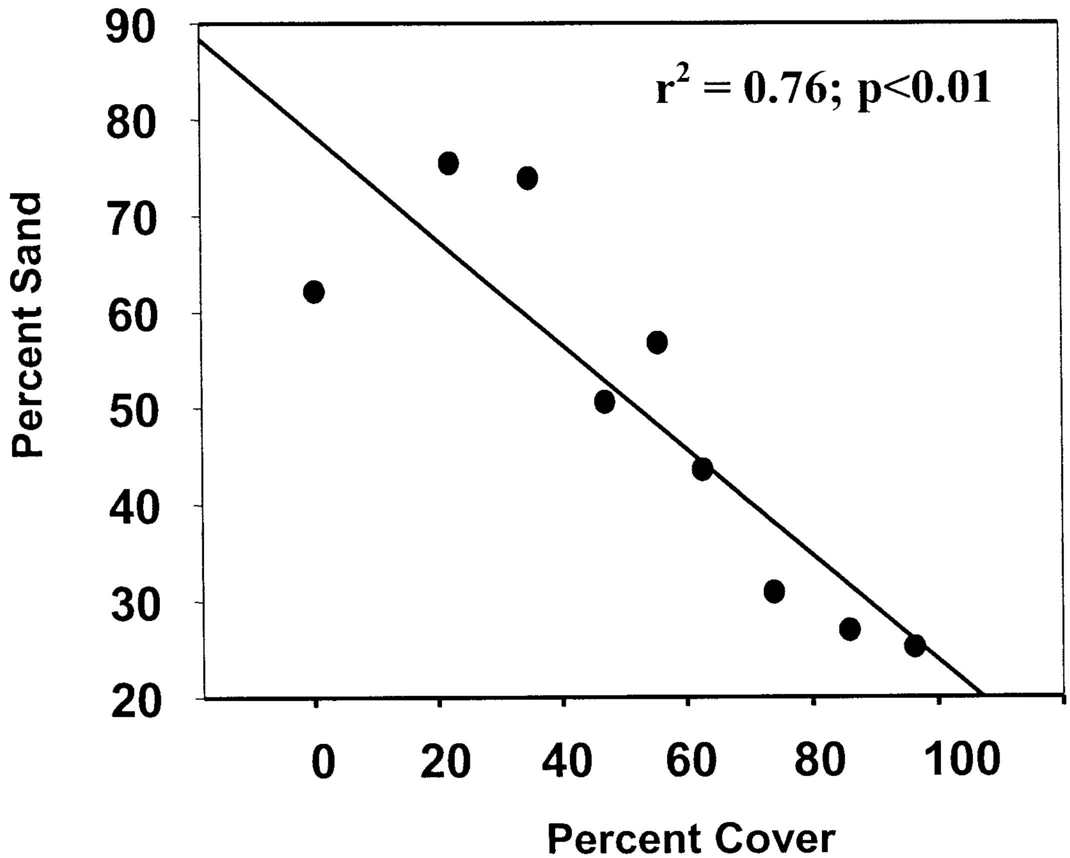

Percent Substrate
50
40
30
20
10
0
0 20 40 60 80 100
Percent Cover
Fine; $r^2 = 0.75$; $p<0.01$
Coarse; $r^2 = 0.47$; $p<0.05$
Medium; $r^2 = 0.79$; $p<0.01$

Figure 2. Percent sand found in streams studied based on percent riparian zone cover. Locations with less riparian cover had a higher build-up of sand in their streambeds



$r^2 = 0.76; p<0.01$
Percent Sand
90
80
70
60
50
40
30
20
0
20
40
60
80
100
Percent Cover

Figure 3. Percentage of full sunlight reaching substrate depth. Streams containing 40 % or more intact riparian zone cover received less than 5 % full sunlight.

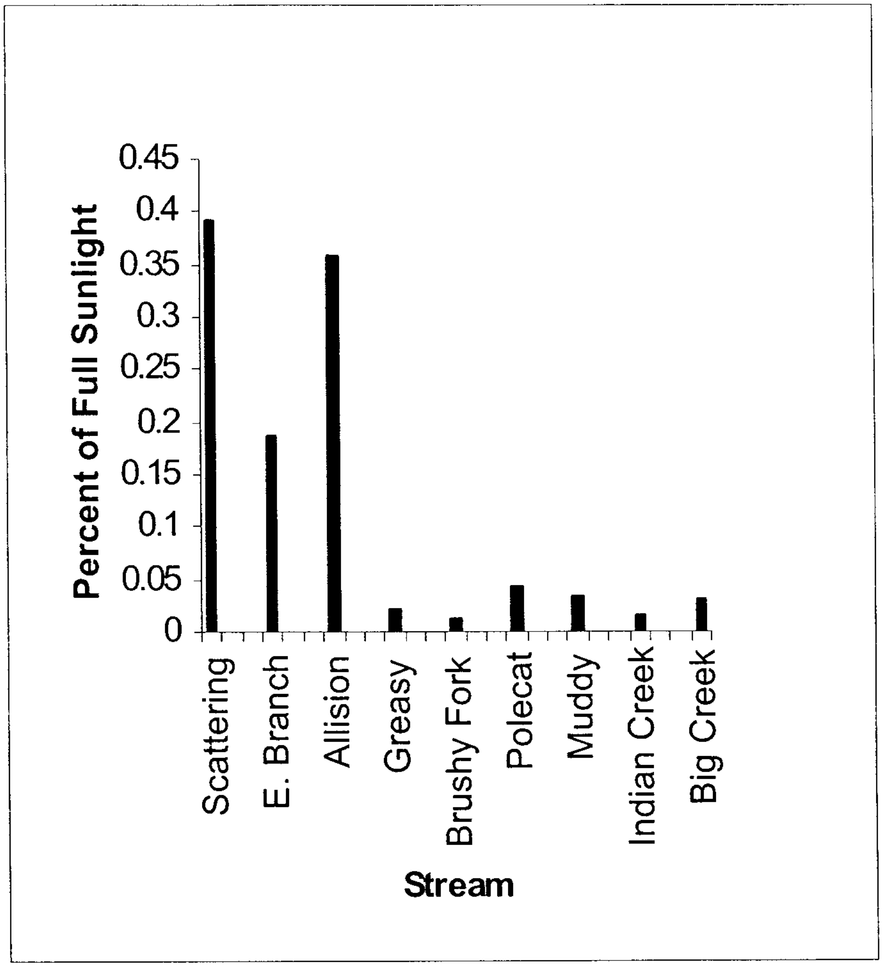

Percent of Full Sunlight
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
Scattering
E. Branch
Allision
Greasy
Brushy Fork
Polecat
Muddy
Indian Creek
Big Creek
Stream

Figure 4. Percentage of full sunlight reaching the surface level of the studied streams. Streams with less than 40 % intact riparian zone cover received at least 60 % full sunlight.

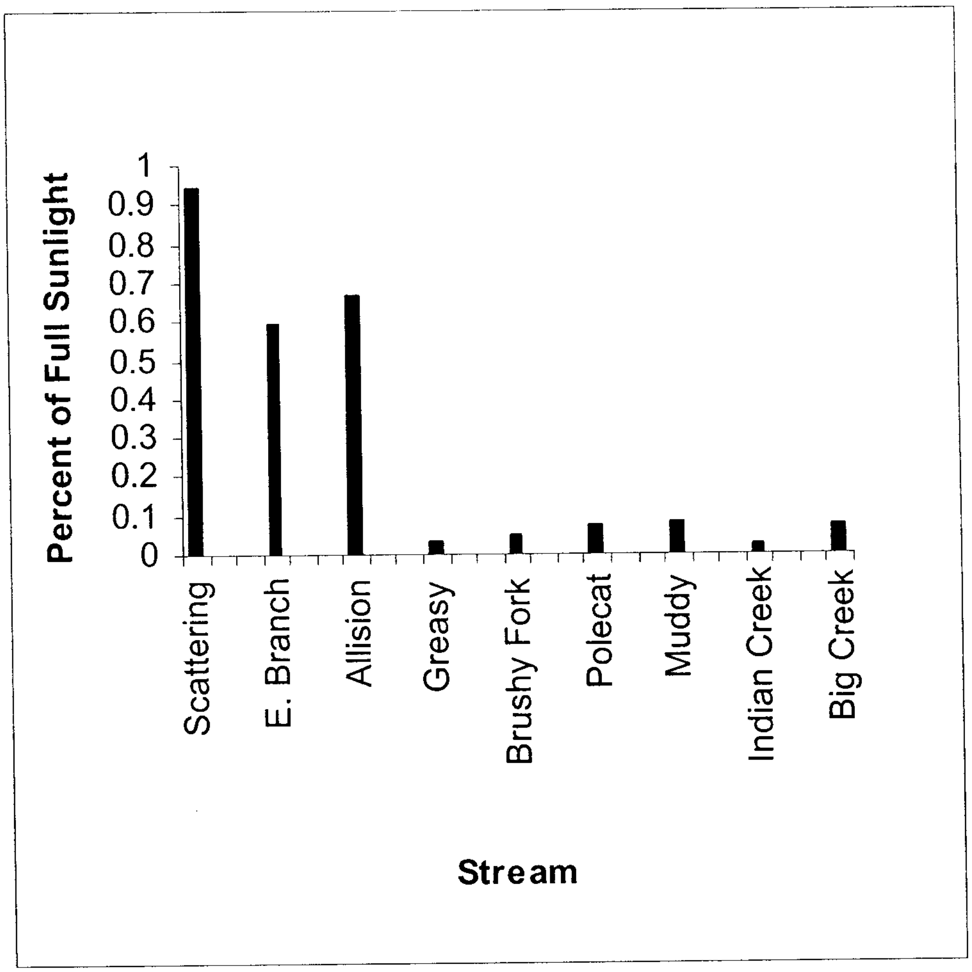
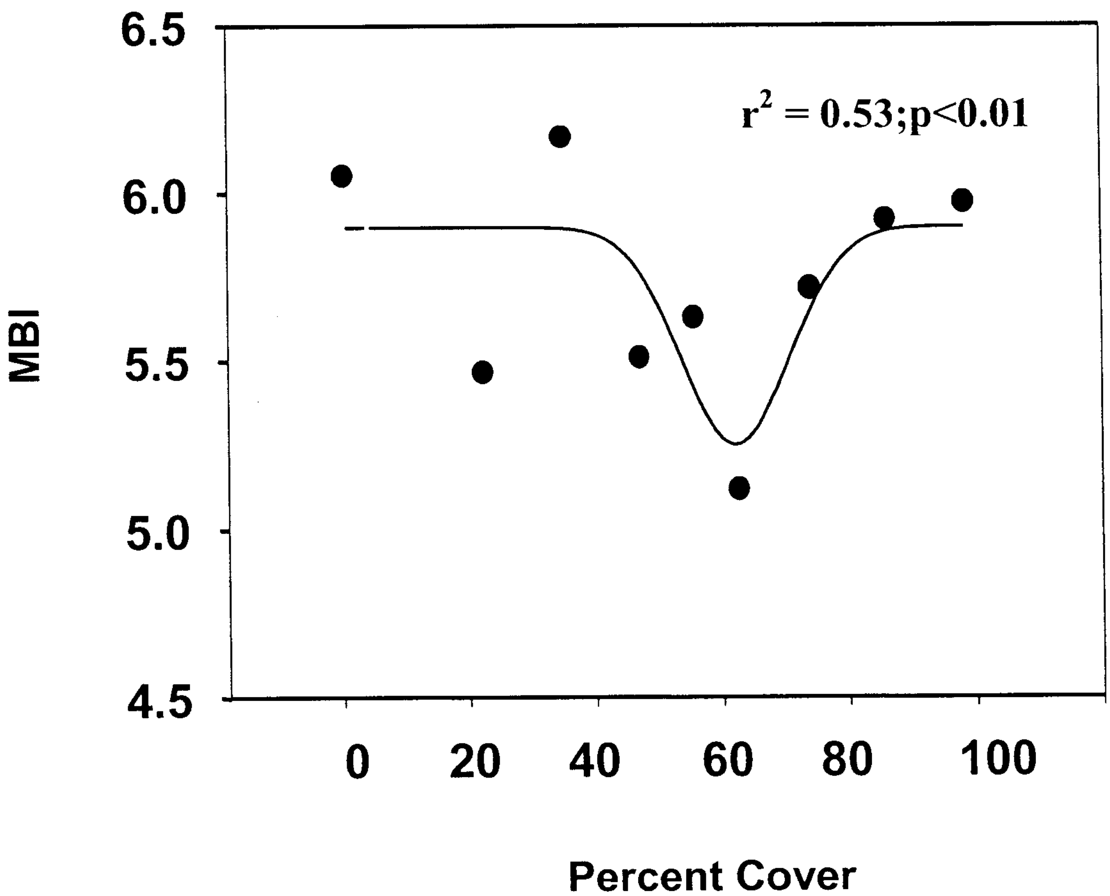

Percent of Full Sunlight
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Scattering
E. Branch
Allision
Greasy
Brushy Fork
Polecat
Muddy
Indian Creek
Big Creek
Stream

Figure 5. Macroinvertebrate biotic index plotted against percent riparian cover. Streams with 40–60 % intact riparian forest cover had the lowest overall MBI scores indicating the presence of a greater number of pollution sensitive species.



6.5
6.0
5.5
5.0
4.5
MBI
r² = 0.53;p<0.01
0
20
40
60
80
100
Percent Cover

Figure 6. Percentage of invertebrates classified as shredders plotted in relation to percent riparian zone cover. Shredder populations were found to decrease significantly with an increase in riparian zone cover, which is not expected to occur.

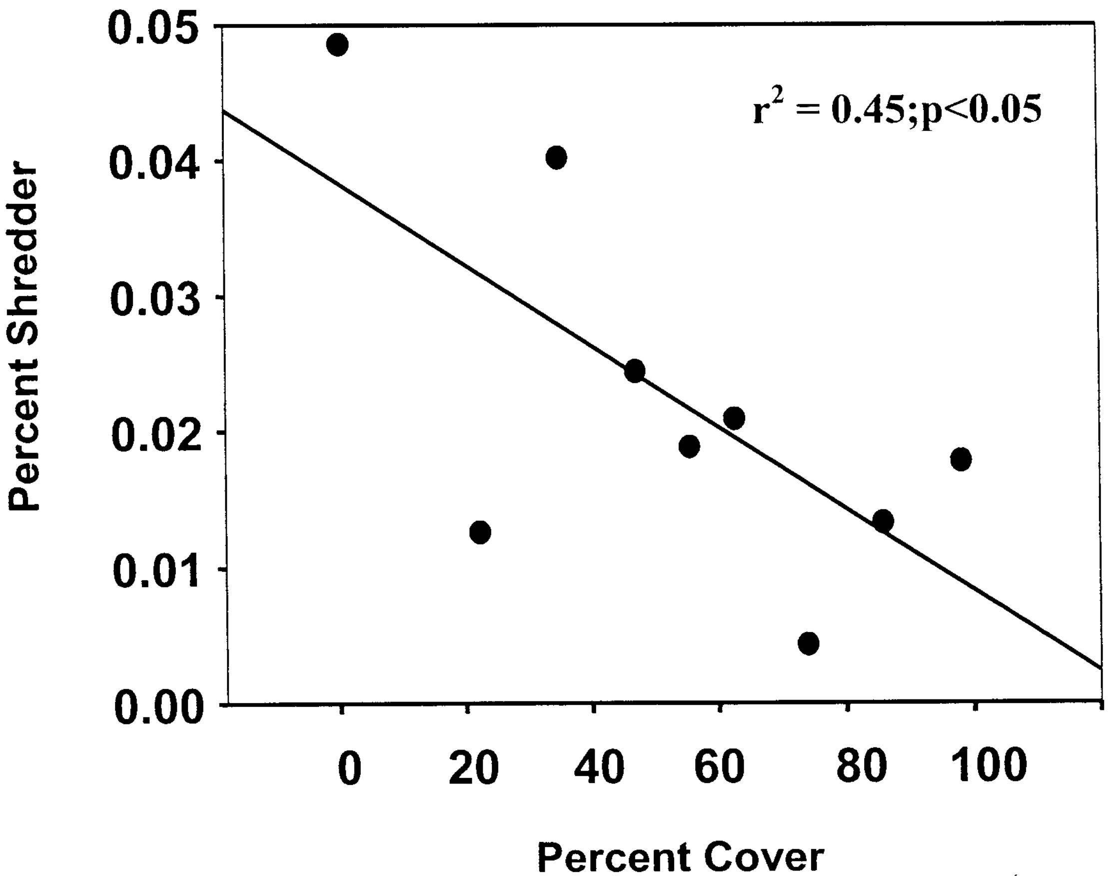
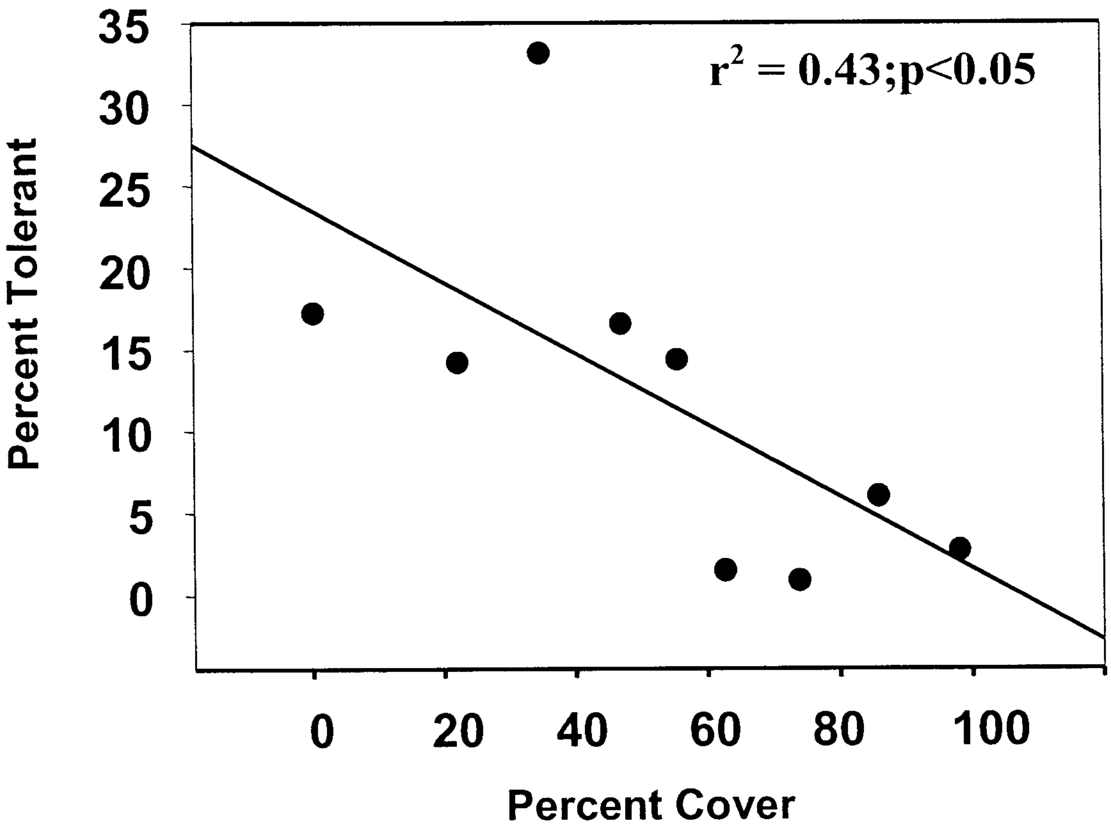
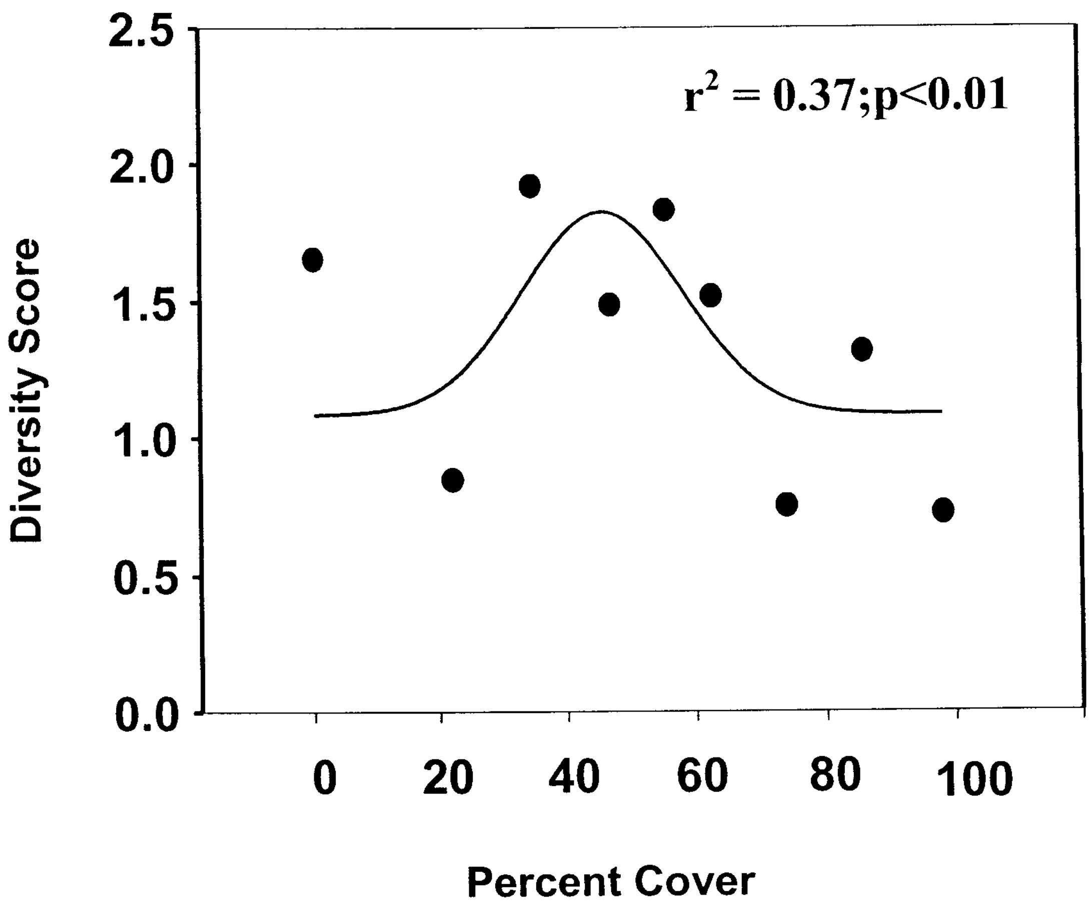

0.05
0.04
0.03
0.02
0.01
0.00
Percent Shredder
r2 = 0.45;p<0.05
0
20
40
60
80
100
Percent Cover

Figure 7. Percentage of families tolerant of environmental perturbations found in streams studied plotted in comparison to percent riparian zone cover. As expected there is a decrease in tolerant, and thus increase in intolerant families as percent cover increases.



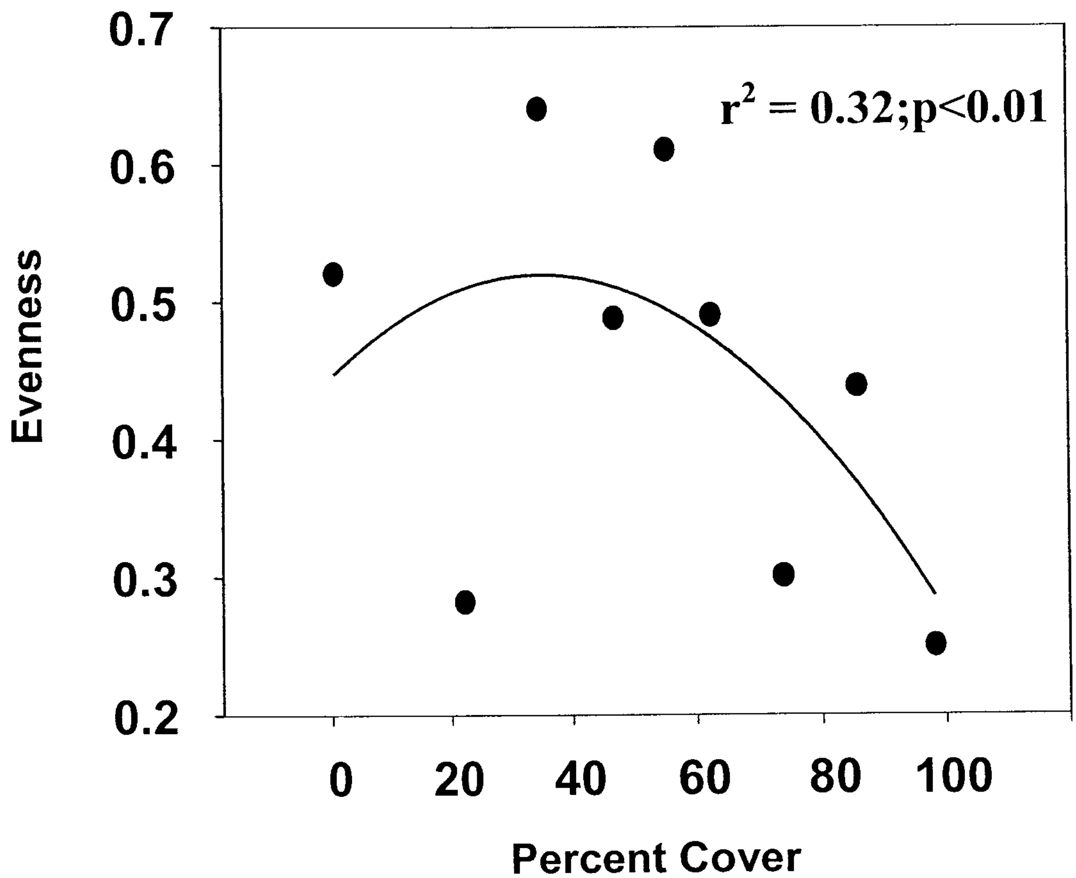
$r^2 = 0.43; p<0.05$
Percent Tolerant
35
30
25
20
15
10
5
0
0
20
40
60
80
100
Percent Cover

Figure 8. Diversity, as calculated by the Shannon-Weaver Index plotted against percent riparian zone cover. Results identified streams with 40 – 60 % canopy cover to have the highest diversity scores, and thus, more equally mixed and rich communities.



2.5
2.0
1.5
1.0
0.5
0.0
Diversity Score
r² = 0.37;p<0.01
0
20
40
60
80
100
Percent Cover

Figure 9. Evenness of invertebrate communities sampled plotted against percent intact riparian zone cover. In general, the highest evenness scores, and thus the invertebrate communities with a measure of biodiversity that is fairly equal numerically, are found to occur in streams with a midrange of riparian zone cover.


0.7
0.6
0.5
0.4
0.3
0.2
Evenness
r² = 0.32;p<0.01
0
20
40
60
80
100
Percent Cover